Uranus Global Reference Atmospheric Model (Uranus-GRAM)

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Uranus-GRAM Overview

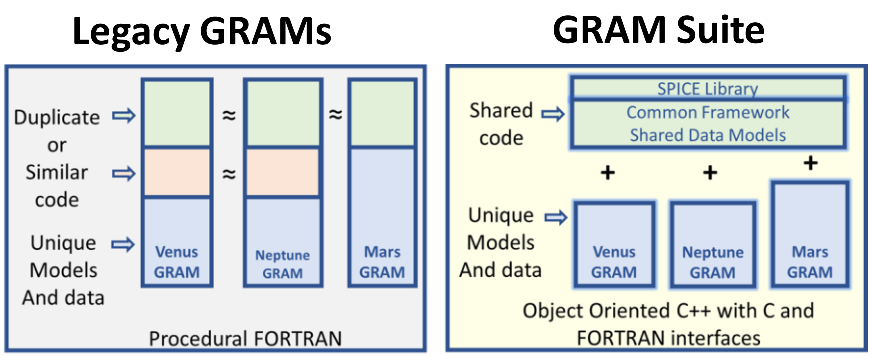
- Developed by the Natural Environments Branch at NASA Marshall Space Flight Center, the Atmospheric Flight and Entry Systems Branch at NASA Langley Research Center, and the Aerothermodynamics Branch at the NASA Ames Research Center
- Engineering-oriented atmospheric model that estimates mean values and statistical variations of atmospheric properties for Uranus
- Outputs include atmospheric density, temperature, pressure, and chemical composition along a user-defined path
- Provides dispersions of density
- Can be integrated into high fidelity flight dynamic simulations of launch, entry, descent and landing (EDL), aerobraking and aerocapture

Uranus-GRAM Overview (Continued)

- Optional trajectory input file consisting of time, height, latitude, and longitude can be used to provide the Uranus-GRAM trajectory path
- Optional auxiliary profile consisting of height, latitude, longitude, temperature, pressure, density, eastward wind, and northward wind may be used to replace model data in Uranus-GRAM
- Not a forecast model
- Part of the GRAM Suite and shares a common software core with the other planetary GRAMs while maintaining Uranus specific models
- Software release package incudes Uranus-GRAM User Guide, GRAM Programmer's Manual, and examples and tests for successful implementation of Uranus-GRAM
- GRAM Suite is available through the NASA Software Catalog https://software.nasa.gov/software/MFS-33888-1

GRAM Suite

- Common object-oriented C++ framework
- Includes a common GRAM library of data models and utilities
  - Reduces duplicated code
  - Ensures consistent constants across all GRAMs
  - Simplifies bug fixes
  - Streamlines the interface with trajectory codes
- Includes C++ library with C and Fortran interfaces which can be incorporated in a trajectory (or orbit propagation) code



Uranus-GRAM Features

- Uranus-GRAM takes advantage of major code modifications made to the GRAMs. Important features include:
  - GRAM ephemeris has been upgraded to the NASA Navigation and Ancillary Information Facility (NAIF) Spacecraft Planet Instrument C-matrix Events (SPICE) toolkit (version N0066) for increased accuracy
    - Use of the NAIF SPICE library requires the Uranus-GRAM user to download the latest SPICE data before using Uranus-GRAM
  - Output files are provided in two formats: a comma separated value file and a LIST file
  - Speed of sound calculations have been improved
    - GRAM Suite includes an improved methodology for computing γ the ratio of specific heats $\frac{C_p}{C_v}$, for a given constituent gas mixture, involving temperature and pressure dependent tables of C_p specific heat capacity of a gaseous mixture for isobaric processes and C_v specific heat capacity of a gaseous mixture for isochoric processes evaluated in run-time for the current constituent combination

Uranus-GRAM Atmospheric Data

- Atmospheric density, temperature, pressure, and chemical composition as a function of height are characterized by the Uranus Atmospheric Model developed by the NASA Ames Research Center (ARC)[1,2]
  - ARC Uranus Atmospheric Model is based on Voyager radio science, Infrared Interferometer Spectrometer and Radiometer (IRIS), and Ultraviolet Spectrometer (UVS) data from the Voyager 2 fly-by of Uranus that occurred on January 24, 1986[3,4,5]
- Includes chemical composition for helium, hydrogen, and methane
- Does not include wind data
- Users of this Voyager era-derived model data should be mindful that there is evidence for significant seasonal variation in the thermal profiles (to be expected since Uranus' axis-of-rotation is nearly in its orbital plane)[6]

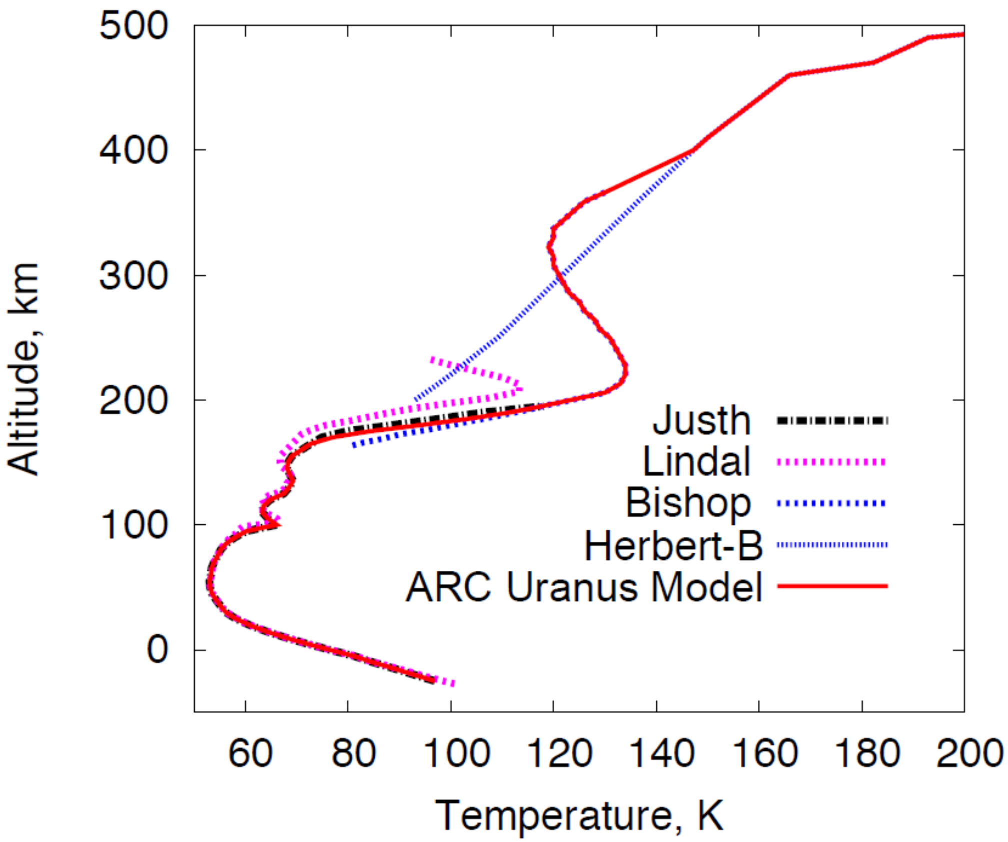
ARC Uranus Atmospheric Model

- ARC Uranus Atmospheric Model was created by combining the mole fraction, pressure, and density data from three data sources[3,4,5] which provides the information necessary to define the equilibrium atmospheric state
  - Lower atmosphere data (–27.5 km to 323.5 km altitude) from Lindal et al.[3]
  - Upper atmosphere data (200 to 7,000 km altitude) from Herbert et al.[4]
  - Upper atmosphere data contained in Herbert et al.[4] superseded by data from Bishop et al.[5] for the 162.6 to 366.1 km altitude region
- Chemical Equilibrium with Applications (CEA) program[7,8] was then used to calculate all remaining thermodynamic and transport properties contained in the ARC Uranus Atmospheric Model

ARC Uranus Atmospheric Model - Continued

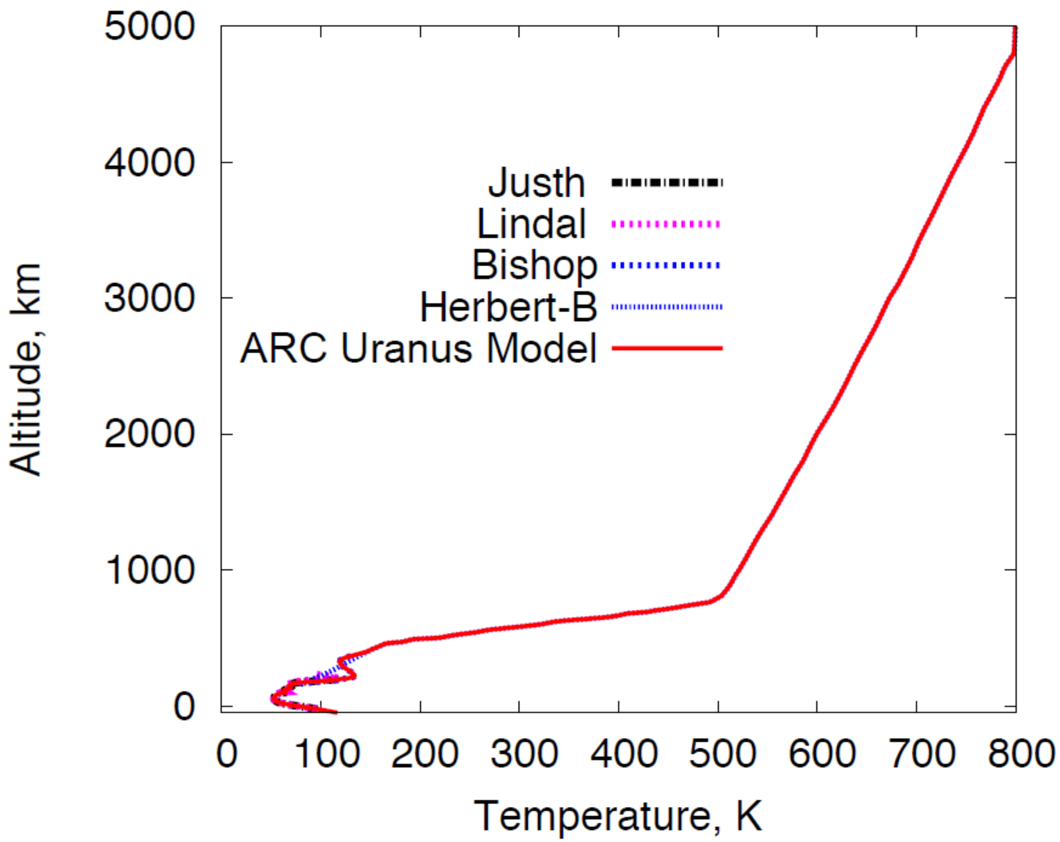
- Significant limitation in the CEA program is that polynomials only provide values for a temperature range from 200° K to 20,000° K and do not model methane phase change
  - Atmosphere of Uranus can reach temperatures below 50° K which will break CEA's polynomial fits
  - To address this limitation CEA was modified with special low temperature routines for atomic hydrogen, molecular hydrogen, and helium
- Process of combining the three data sources and the resulting ARC Uranus Atmospheric Model profile is shown in slides 9 through 12
  - Continuity issues between the Lindal et al.[3] and Bishop et al.[5] data was resolved by adding a profile (labeled Justh) shown in slides 9 through 12
    - Profile produced by utilizing Uranus temperature versus pressure profile data from Lindal[9] in a hydrostatic code to compute temperature, pressure, and density versus geometric height

ARC Uranus Atmospheric Model - Temperature Profile



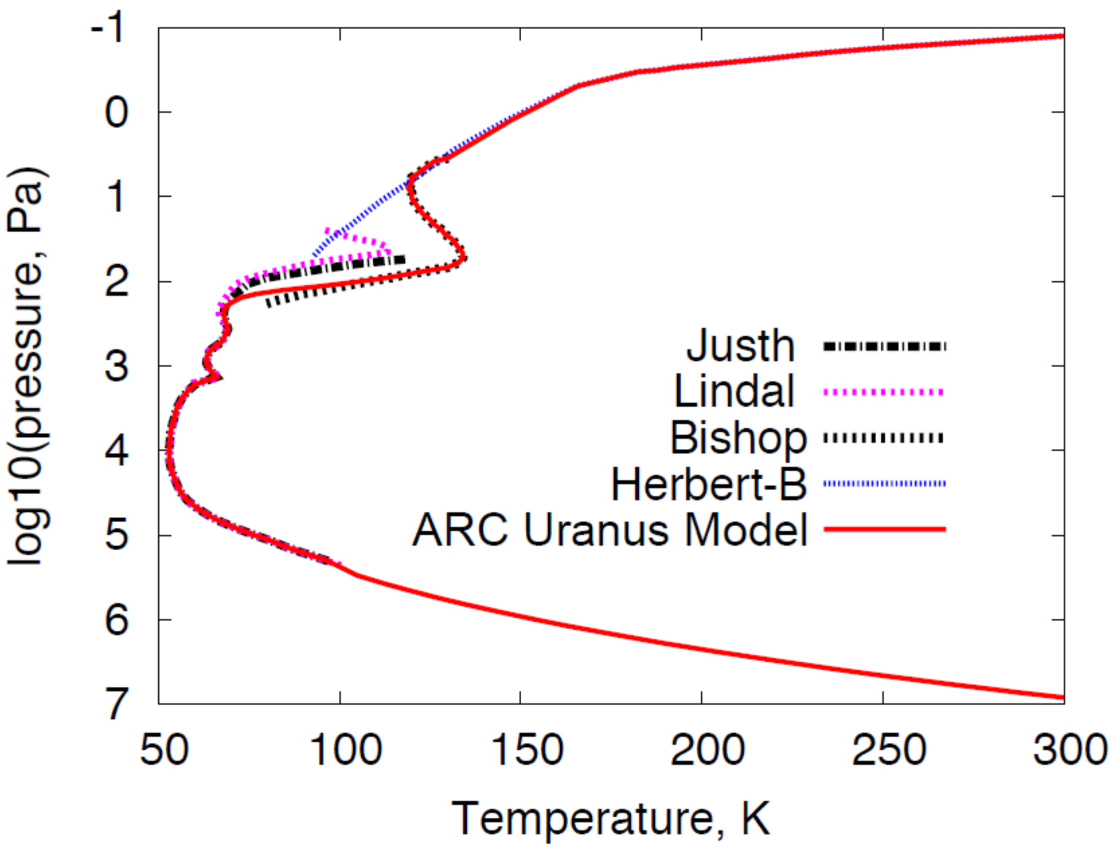
Altitude versus temperature up to 500 km altitude for each data source and the ARC Uranus Atmospheric Model

ARC Uranus Atmospheric Model - Temperature Profile



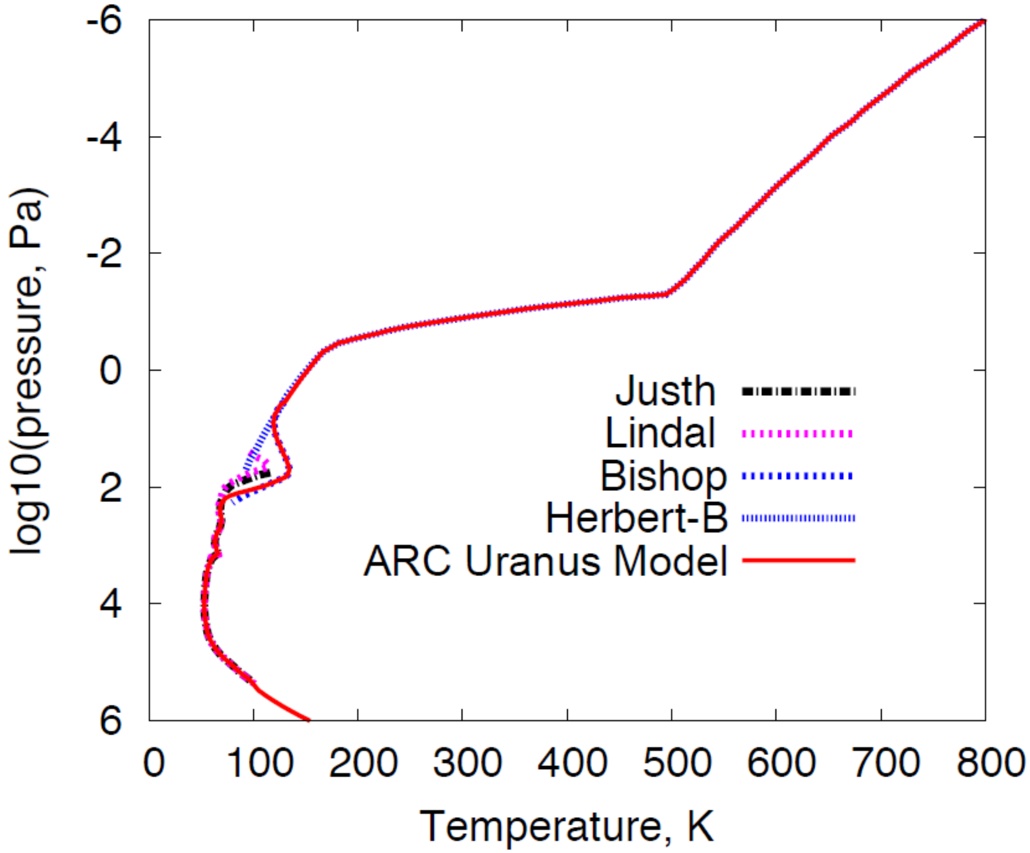
Altitude versus temperature over the full altitude range for each data source and the ARC Uranus Atmospheric Model

ARC Uranus Atmospheric Model - Temperature Profile



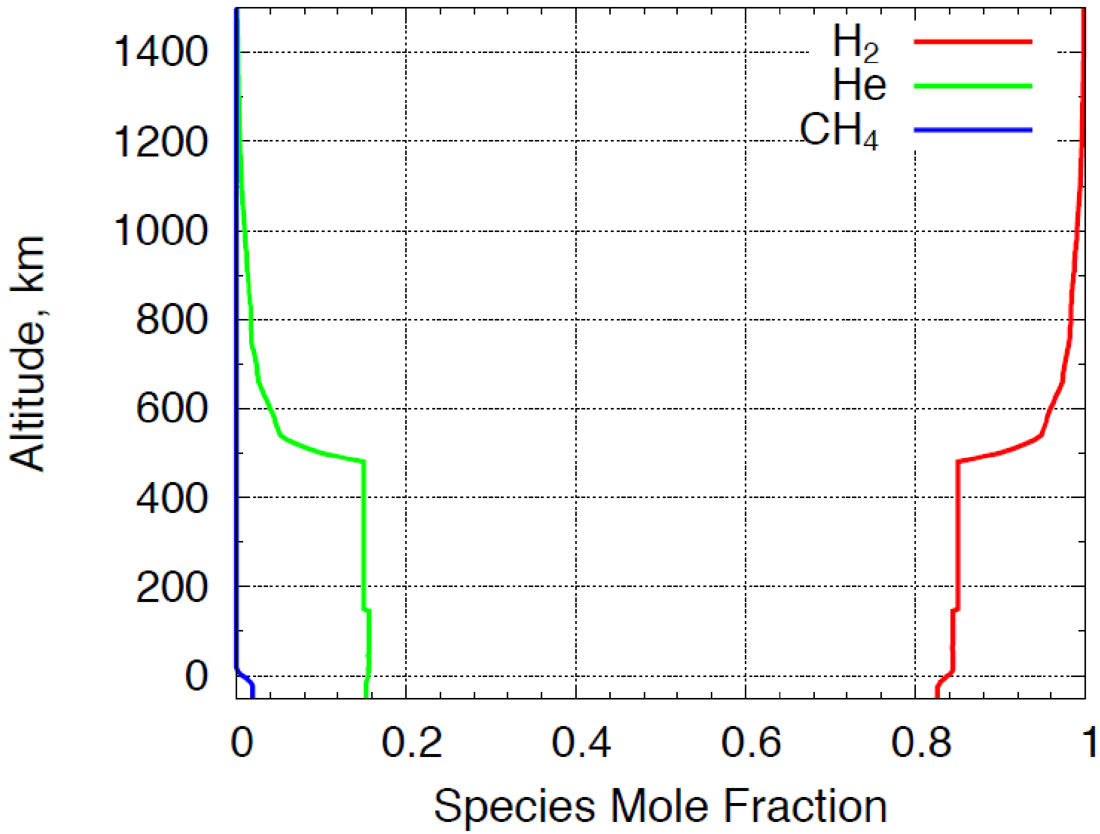
Pressure versus temperature up to 500 km altitude for each data source and the ARC Uranus Atmospheric Model.

ARC Uranus Atmospheric Model - Temperature Profile



Pressure versus temperature over the full altitude range for each data source and the ARC Uranus Atmospheric Model.

ARC Uranus Atmospheric Model – Atmospheric Constituents



Altitude vs. Uranus atmospheric mole fractions. Default gas mole fraction: H_2 0.85, He 0.15

Uranus-GRAM Density Perturbations

- Uranus-GRAM density perturbation magnitudes are estimated using:

$$\rho' = \rho_0 \left(1 + R' P_F P_U\right)$$

and

$$R' = e^{-S} R + X\sqrt{1 - e^{-2S}}$$

  – where:
    - ρ' = perturbed value of atmospheric density
    - ρ_0 = mean value of atmospheric density
    - R' = correlation factor for the current time step
    - P_F = modeled perturbation factor (typically height dependent)
    - P_U = user-supplied perturbation multiplier
    - S = relative displacement from the last time step using NS, EW, vertical movement, and winds (when modeled)
    - R = correlation factor for the previous time step
    - X = value provided by a random number generator

Uranus-GRAM Gravity Parameters

- Uranus-GRAM utilizes Uranus gravity parameter data from Lindal et al.[3] that was used when constructing the ARC Uranus Atmospheric Model

	Label	Units	Value
Gravitational Parameter	GM	km^3/s^2	5793964
Mean Equatorial Radius	R_e	km	25559.0
Mean Polar Radius	R_p	km	24973.0
J2 harmonic	J_2	km^5/s^2	0.00334129
Period (*retrograde*)		s	-62063.71199

Summary

- GRAMs are frequently used toolsets and vital in assessing effects of atmospheres on interplanetary spacecraft during the program life cycle process
- Planned Uranus-GRAM upgrades will occur in the near future
  - Ongoing discussions with modeling groups within NASA and academia regarding status of their Uranus models
  - Aligning Uranus-GRAM upgrades with planetary mission needs and priorities identified by the Planetary Science and Astrobiology Decadal Survey 2023-2032
  - Will conduct discussions with potential Uranus probe and atmospheric mission teams to determine potential mission support by the GRAM team, utilization of collected atmospheric data, and needed GRAM upgrades

References

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